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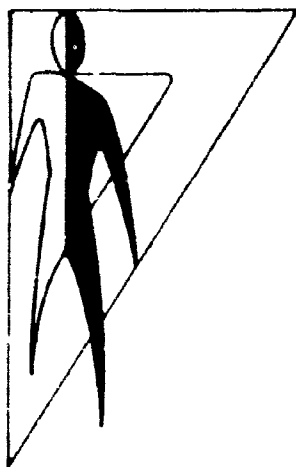
Technical Memorandum 4-65

AUDITORY LOCALIZATION OF NOISES

Robert W. Bauer
Raymond F. Blackmer

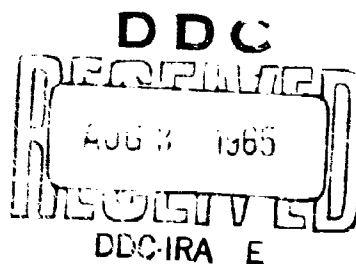
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HUMAN ENGINEERING LABORATORIES



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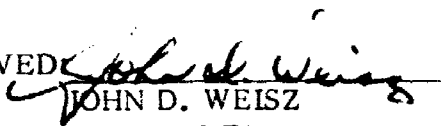
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January 1965

APPROVED

A handwritten signature in dark ink, appearing to read "John D. Weisz", is written over the printed name and title.

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ABSTRACT

This report summarizes three studies of unaided auditory localization of fixed noise sources. Pointing was as accurate as aiming at auditory targets in darkness. Elevation errors were not significantly larger than azimuth errors. Subjects with hearing deviations (defects) performed as well as non-deviant subjects (normals) in auditory localization.

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AUDITORY LOCALIZATION OF NOISES

INTRODUCTION

This report summarizes three recent studies of auditory localization. These were studies IV, V, and VI in a program of research on auditory localization of noises, initiated by the U. S. Army Human Engineering Laboratories in 1963. The first three studies (1) involved the auditory localization of moving noise sources. The three studies reported here were concerned with stationary noise sources. Study IV measured the accuracy of auditory aiming, and compared it with accuracy in auditory pointing, visual aiming, and visual pointing. Study V attempted to replicate the findings of Study IV with a different response method and a different method of data analysis. Study VI was another replication, intended to check inconsistencies between results in the previous two studies, and to discriminate between three alternative explanations of the results obtained previously. All three of these studies involved azimuth and elevation of stationary noise sources at a constant distance in darkness with unaided human hearing.

These studies were conducted between 12 November 1963 and 11 August 1964, at a level, grass-covered site at Aberdeen Proving Ground, Md. The subject stood on a platform fixed so his head was approximately 30 feet in radius distance from a display of lights and buzzers arranged in both azimuth and elevation (Fig. 1). Figure 2 shows the azimuth and elevation stimulus positions schematically.



Fig. 1. AZIMUTH AND ELEVATION DISPLAY

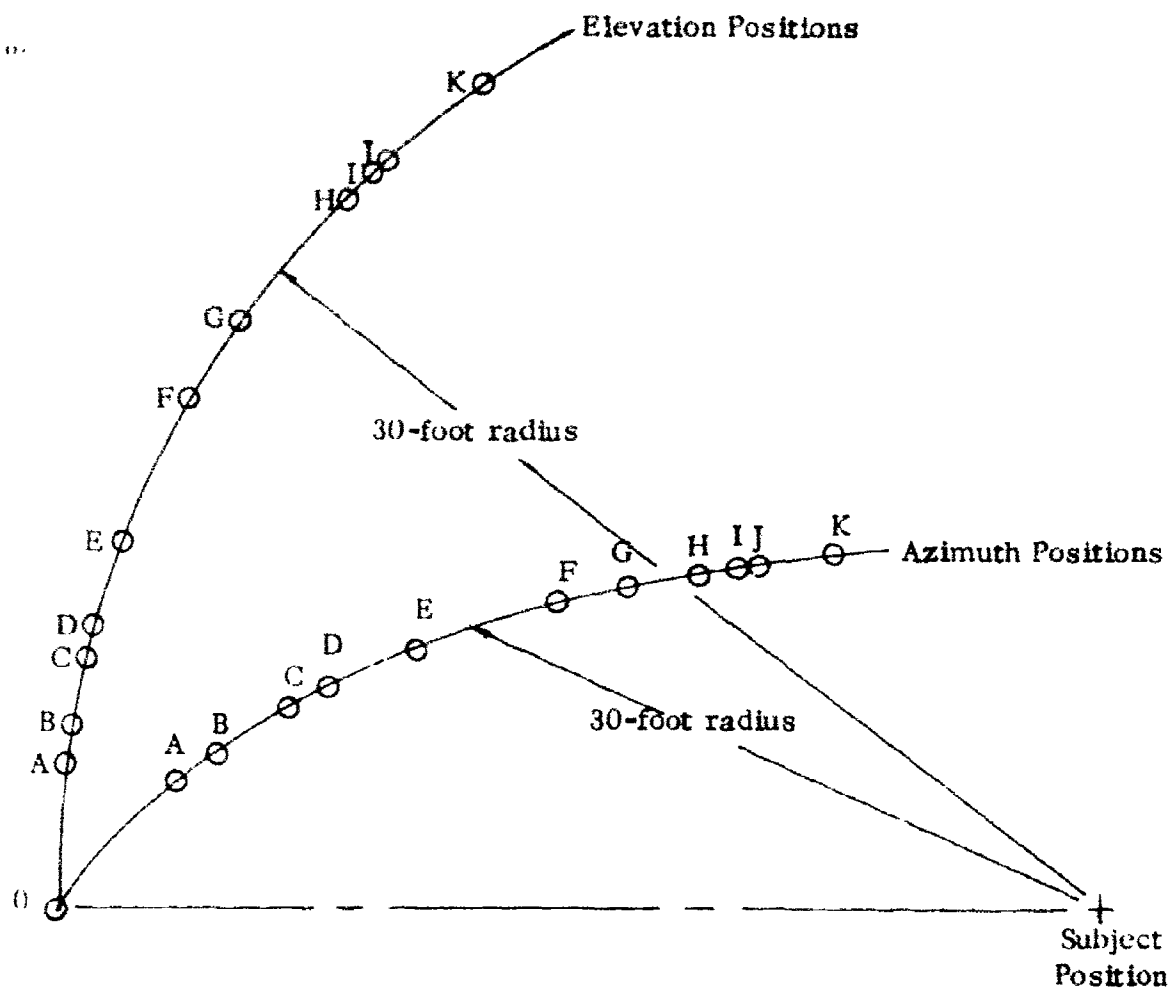


Fig. 2. AZIMUTH AND ELEVATION POSITIONS

STUDY IV

PURPOSE AND HYPOTHESES

Stimulus Modes and Responses

It is reasonable to assume that visual aiming would be more accurate than auditory pointing. Furthermore, the methods of measurement used in auditory localization studies are generally too crude to register the relatively small errors involved in visual aiming. These considerations, and the considerable military research on visual aiming accuracy, seemed to preclude consideration of visual aiming accuracy in this study. However, there were unresolved questions about aiming at auditory stimuli and about the accuracy of this response as compared with accuracy in auditory pointing and visual aiming.

Auditory aiming, like visual aiming, was defined as aligning a pointer between the subject's (S's) head and eyes and a target in the dark environment. The pointer was mounted, and it had a peep sight and a bead for aiming. Unlike visual aiming, auditory aiming involved no visible target, but merely the S's selection of the direction of the noise source audible in the dark environment. By contrast with visual aiming and auditory aiming, auditory pointing required aligning the same pointer with the sound source but without aligning the head and eyes -- that is, without using the peep sight. Visual pointing, similarly, required aligning the pointer with a visible target, but without using the peep sight.

Elevation and Azimuth

The previous research conducted by the Human Engineering Laboratories (HEL), as well as most of the scientific literature on auditory localization, was concerned only with azimuth. Elevation errors might be expected to be larger, since the horizontal axis of a standing S's ears facilitates discrimination in the horizontal plane but not in the vertical plane. Furthermore, reflection from the earth's surface of elevated noises may selectively distort perception in the vertical plane.

Hypotheses

These considerations of stimulus modes and responses and of elevation and azimuth led to four hypotheses:

- a. Pointing at visual targets is significantly less accurate than aiming.
- b. Pointing at auditory targets is no less accurate than aiming.
- c. Elevation errors in pointing to a visual target are no larger than azimuth errors.
- d. Elevation errors in pointing to an auditory target are larger than azimuth errors.

METHOD

Subjects

Eighty enlisted men were given Rudmose ARJ-4 automatic audiometric examinations prior to participation. They were tested at frequencies of 500, 1000, 2000, 3000, 4000, and 6000 cycles per second (cps). Approximately half the Ss showed deviations ranging from 15 dB to 70 dB at one or more of the frequency levels tested. No Ss were eliminated on these grounds, but these deviations were recorded and classified for later analysis.

Procedure

Under open-field conditions and in darkness, Ss were asked to respond to either noise stimuli (buzzers) or small lights arranged at a constant radius (30 feet) from the S's position. Lights and buzzers were arranged in pairs, one pair at each of 11 points in azimuth and another pair at each of 11 corresponding points in elevation. Each are subtended a total of 54° , as diagrammed in Figure 2.

Subjects were assigned to four different experimental groups arbitrarily selected by their commanding officer. Forty Ss were tested with lights only, 40 Ss with buzzers only. These two groups were further subdivided into elevation and azimuth groups: 20 Ss on visual elevation, 20 on visual azimuth, 20 on auditory elevation, and 20 on auditory azimuth. Each S was required to give

TABLE 1
Results of Study IV

Modality	Response	Plane	Mean Absolute Error (in degrees)	75th Percentile (in degrees)	95th Percentile (in degrees)
Auditory	Pointing	Elevation	14.5 ^a	19.0	47.5
"	"	Azimuth	3.5	5.5	9.5
"	Aiming	Elevation	18.5	27.5	48.5
"	"	Azimuth	4.0	6.0	11.0
Visual	Pointing	Elevation	5.0	6.5	12.0
"	"	Azimuth	0.5	1.5	2.0
"	Aiming	Elevation	0.5	0.5	1.5
"	"	Azimuth	0.0	0.5	1.0

^aAll measures were rounded to the nearest half degree, consistent with the accuracy of original measurements: e.g., the calculated numerical value of the last figure in the first column was 0.1°, which was rounded to 0.0°.

five "pointing" and five "aiming" responses so that his accuracy in pointing could be compared with his accuracy in aiming. Thus each S served as his own (matched) control on comparisons of pointing with aiming, but was compared with an independent group in other modality-direction combinations, and no single stimulus was repeated with the same S. During the S's response, the stimulus (light or buzzer) remained on until the S was satisfied that his response was accurate.

The stimuli were presented in a random pattern, and order of pointing and aiming was alternated. Each S responded to only one mode of stimulation (auditory or visual), and only one direction parameter (elevation or azimuth). The same azimuth table was used for all responses. A hinged top permitted fixing it in a vertical position for elevation measures. The buzzers were metal-cased, powered by 6 - 8 volts AC, and the lights were 21-candlepower lamps with S-8 bulbs.

RESULTS

Analysis of variance revealed significant ($p < .001$) interaction between modality and direction. Further examination showed the nature of this interaction. Elevation errors were generally larger than azimuth errors, and especially larger with auditory stimuli (Table 1).

The results confirmed three of the four hypotheses tested:

- a. The first hypothesis -- that pointing at visual targets is significantly less accurate than aiming -- was confirmed. Visual pointing was significantly less accurate ($p < .001$).
- b. The second (null) hypothesis -- that pointing at auditory targets is no less accurate than aiming -- was also upheld. Auditory pointing and aiming did not differ significantly.
- c. Only the third hypothesis -- that elevation errors in pointing to a visual target are no larger than azimuth errors -- was not confirmed. The elevation errors were larger ($p < .005$).
- d. The last hypothesis -- that elevation errors in pointing to an auditory target are larger than azimuth errors -- was confirmed. The elevation errors were larger ($p < .005$).

STUDY V

PURPOSE AND HYPOTHESES

Response Measurement

Study IV used a display which presented continuous fixed noises (buzzers) or lights over total arcs of 54° in elevation or azimuth, separately. An adapted azimuth table with a rotating pointer was used to measure responses. Study V used a different response and a different method of data analysis with the same display. The purpose was to compare results obtained previously on the adapted azimuth table with data obtained by a variation of the method of constant stimuli.

Elevation and Azimuth

A further purpose of Study V was to replicate the results of Study IV, which indicated that errors in locating auditory targets were much larger in elevation than in azimuth.

Hypotheses

These purposes were reduced to three hypotheses:

- a. Errors in locating auditory targets, as measured by the constant-stimuli method, will be similar to errors measured by the previous method.
- b. Absolute errors in locating auditory targets will grow larger as the target reaches higher elevations.
- c. Elevation errors will be larger than azimuth errors.

METHOD

Subjects

The Ss were 35 enlisted men. Each S took repeated audiometric examinations on the Rudmose ARJ-4 automatic audiometer. After four or five audiograms Ss generally gave stable, consistent records indicating reliable measurement. Nine of these Ss deviated from "normal" by 15 dB to 30 dB at one or more of the six frequency levels tested. As in the previous study, no Ss were eliminated on this basis, but the deviations were classified for later data comparisons.

Procedure

Each S stood in an illuminated area of an otherwise-darkened field. Ten noise stimuli (buzzers) were presented to each S in a random order. Five of these noises were selected from the horizontal (azimuth) array in order -- F, J, H, D, B -- and five from the vertical (elevation) array in the same order (Fig. 2). The order of azimuth and elevation presentations was alternated. With each noise stimulus, all 11 light stimuli in the same array (azimuth or elevation) were presented in a random order.

Thus each buzzer was paired with all the light positions. On each pairing of buzzer and light, the S was required to report whether the light was higher or lower than the buzzer (in elevation), or to the right or left of the buzzer (in azimuth). Reports of "same place" were not accepted, even if, as occasionally happened, they were correct.

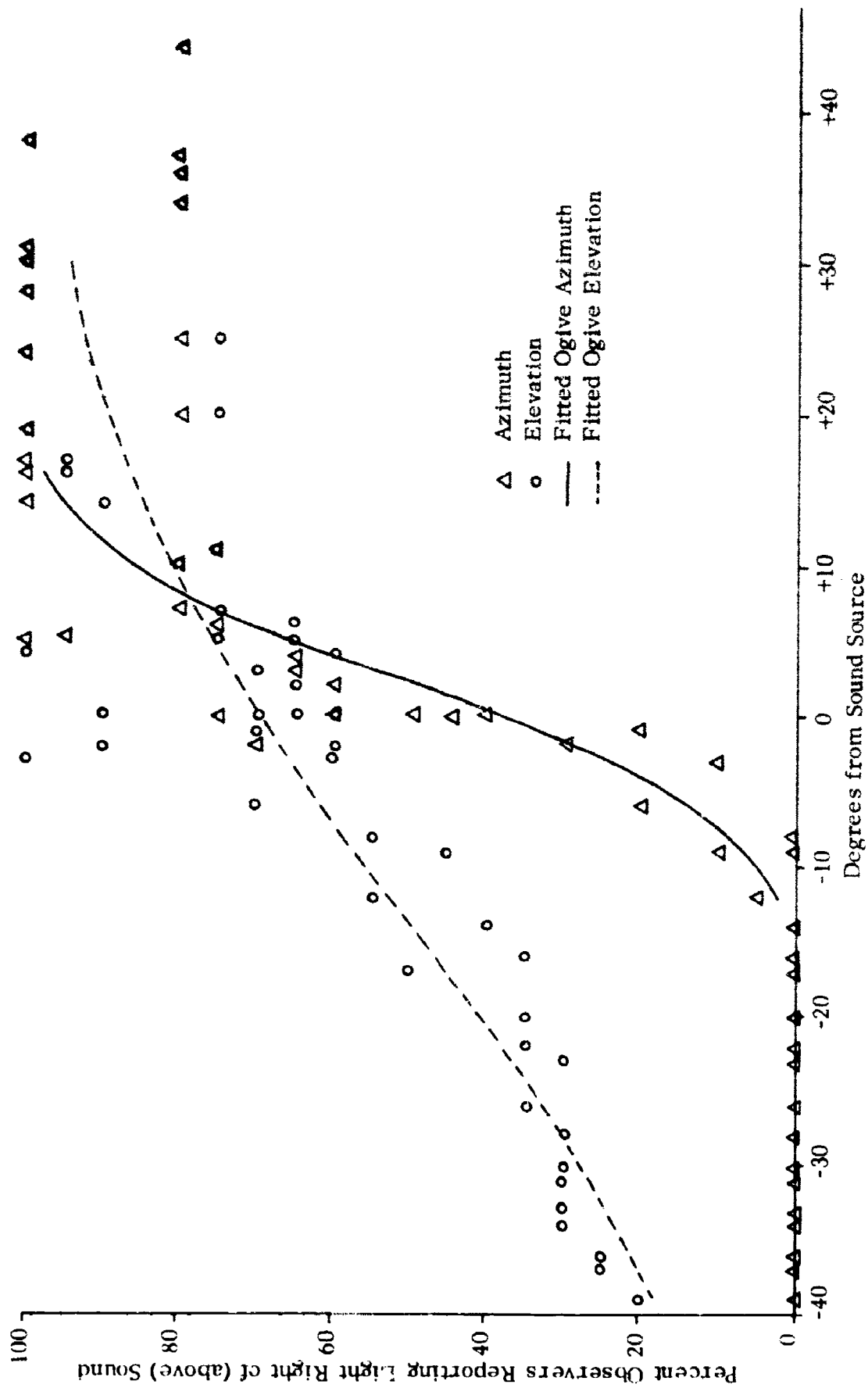


Fig. 3. STUDY IV: STANDING POSITION, COMPOSITE
(All points translated to zero.)

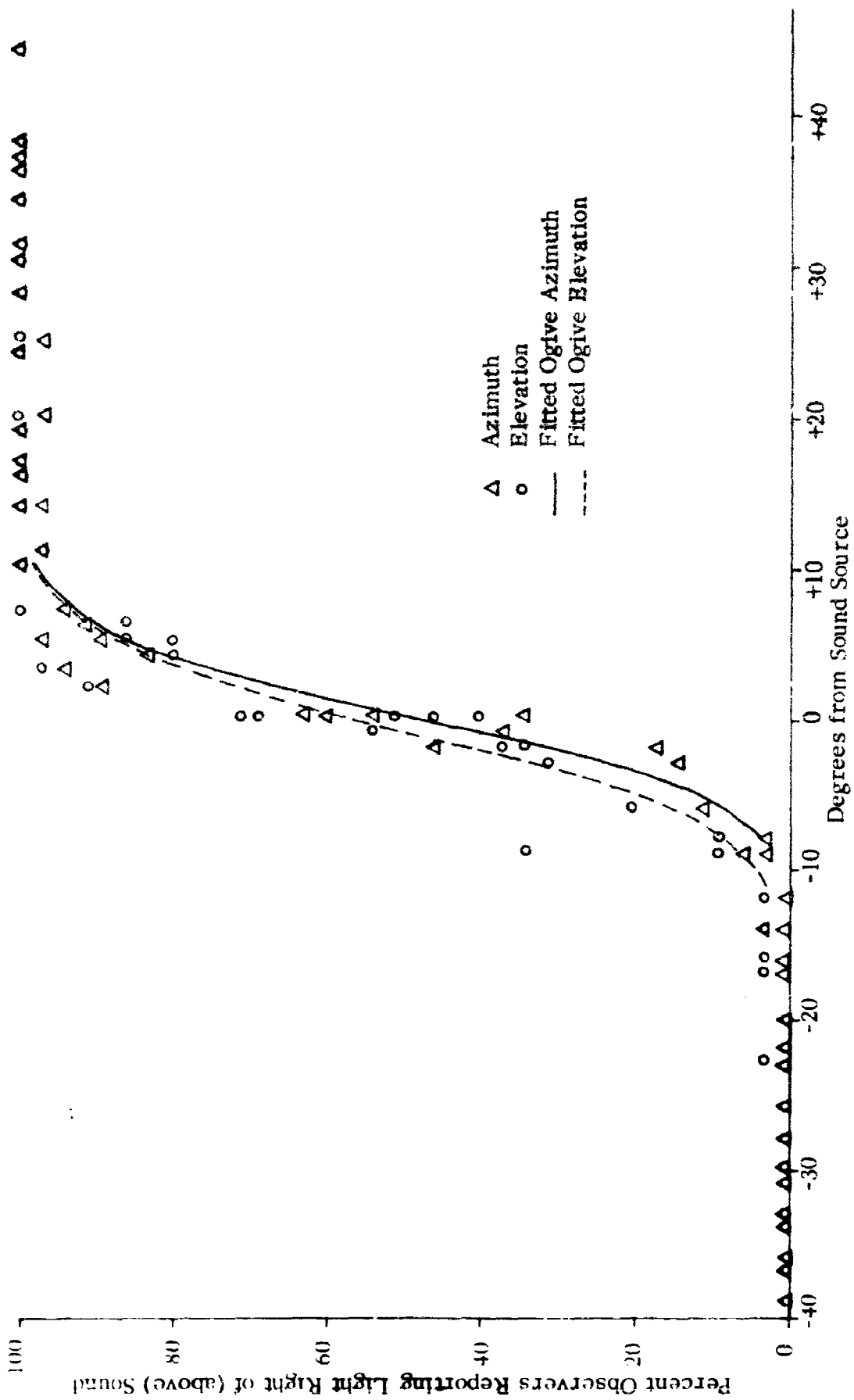


Fig. 4. STUDY V: STANDING POSITION, COMPOSITE
(All points translated to zero.)

RESULTS

Observations were tabulated and plotted as percent of observers reporting the light above buzzer (in elevation), or percent of observers reporting the light to the right of buzzer (in azimuth). Auditory pointing and aiming errors from Study IV were also transformed into judgments above a given point (in elevation) or to the right of a given point (in azimuth). For convenience in comparing results from Study IV with results from Study V, ogives were fitted to these distributions, as shown in Figures 3 and 4. The results of Study V did not show the extreme differences between elevation errors and azimuth errors found in Study IV, and errors were not larger at higher levels of elevation.

The results confirmed only the first of the three hypotheses tested:

- a. The one hypothesis confirmed was that errors in locating auditory targets, as measured by the constant-stimuli method, will be similar to errors measured by the previous method. The results of the two methods were not significantly different.
- b. The second hypothesis -- that absolute errors in locating auditory targets will grow larger as the target reaches higher elevations -- was not confirmed. No such significant difference appeared.
- c. The third hypothesis -- that elevation errors will be larger than azimuth errors -- was not confirmed either. The differences were not significant.

STUDY VI

PURPOSE AND HYPOTHESES

Elevation Versus Azimuth Localization

In the two previous studies of localization, results were not consistent with regard to the hypothesized difference between elevation and azimuth errors. Study IV results showed a significant difference between elevation and azimuth errors, but in Study V, in which a different method of response measurement was used, no such significant difference between elevation and azimuth was found. In Study IV the Ss adjusted a pointer on an adapted azimuth table to indicate elevation or azimuth of a buzzer sounded in darkness. In Study V the Ss judged the relative position of two stimuli appearing simultaneously in the darkness -- a light and a buzzer.

If the difference in results were due to differences between methods of measurement, the larger elevation errors in Study IV would be interpreted as an artifact produced by the use of the adapted azimuth table. There are two other possible explanations. In Study IV, while using the pointer method, the Ss occasionally pointed toward the earth, at angles below 0° , when the noises were actually at positive elevations. This occasional phenomenon suggested a second explanation, that sounds reflected from the grass-covered surface, especially those noises from high elevations, were creating an illusion of sources in the low foreground. The third alternative explanation, based on the horizontal orientation of man's auditory system, suggested that the Ss' standing position in both studies facilitated azimuth localization, but not elevation localization.

To test these explanations, an experiment was designed so that these different explanations would predict different results. The first explanation, involving the difference in instrumentation between Study IV and Study V, would predict results similar to those of Study V when that study's psychophysical method was used. The second explanation, based on reflection from the grass-covered surface, would predict results similar to those of Study IV: larger errors in elevation than in azimuth, regardless of measurement method and regardless of the posture or position of the S. The third explanation, based on position and the horizontal arrangement of the human ears, would predict that azimuth (phenomenal elevation) errors would be greater than elevation (phenomenal azimuth) errors if the S were lying on his side, while true elevation errors would be greater than true azimuth errors if he stood up as in the two previous studies.

Three mutually exclusive hypotheses were therefore stated:

- a. Errors in elevation localization and in azimuth localization will not differ significantly, regardless of S position.
- b. Errors in elevation localization will be larger than errors in azimuth localization, regardless of S position.
- c. Errors in elevation localization will be larger than errors in azimuth localization when S is standing, while errors in azimuth (phenomenal elevation) will be larger than errors in elevation (phenomenal azimuth) when S is lying on his side.

METHOD

Subjects

Thirty enlisted men served as Ss. As in the previous studies, each S was given a series of audiometric examinations on the Rudmose automatic audiometer. Deviations in the resulting audiograms were classified.

Procedure

The stimuli were presented in the evening after dusk. Each S responded from an illuminated area in an otherwise darkened field. Twenty noise stimuli (buzzers) were presented to each S in a random order -- ten with the S standing and ten with the S lying down. For the standing presentation, five noises were selected from the vertical (elevation) array and five from the horizontal (azimuth) array. For the prone presentation, the S reclined on his side on a cloth cot with both ears free for unimpeded reception, and five different noises were selected from both the vertical and the horizontal arrays. Azimuth, elevation, standing position, and reclining position were systematically alternated with alternate Ss.

Each of 11 light stimuli in the same array (elevation or azimuth) with a noise stimulus was presented with that noise stimulus in a random order. For each pairing of light and buzzer, the S was required to report whether the light was higher or lower than the noise or to the right or left of the noise. Reports of "same place" were not accepted, even if, as occasionally happened, the S was correct. The S could observe a buzzer-light combination as often or for as long as he wanted on any trial, but only his final response to each pair was recorded.

RESULTS

Composite results are represented graphically in Figures 5 and 6. For standing observers, Figure 5 presents all elevation and azimuth points, translated to the same zero point, with percent of the observers reporting the point above (or right of) the sound at different deviations from the true (zero) point. Figure 6 presents similar data for reclining observers -- all elevation and azimuth points, translated to the same zero point, with percent of the observers reporting the point above (or right of) the sound at different deviations from the true (zero) point.

Results were similar to those of Study V; that is, there were not the marked differences between azimuth and elevation determinations found in Study IV. Thus the first hypothesis was substantially confirmed; the other two hypotheses, both of which predicted differences between elevation and azimuth errors, were rejected.

DISCUSSION

Response Measurement

The fact that the large difference between elevation errors and azimuth errors found in Study IV was not replicated in Studies V and VI supports the interpretation that this difference was due to the instrumentation and method of measuring responses. The adapted azimuth table in Study IV permitted larger errors and contributed especially to the large elevation errors found in that study. On the other hand, the 54° range of light stimuli used in Studies V and VI restricted the range of errors somewhat, although this method permitted a better comparison of elevation and azimuth errors.

Elevation and Azimuth

Results from Study V and VI, using the modified method of constant stimuli, were remarkably consistent. Comparison of Figures 4, 5, and 6 showed no marked differences between elevation and azimuth errors, regardless of S position, but did show that elevation errors tend to be slightly larger than azimuth errors when the S is standing. What affected these elevation errors most profoundly was apparently the method of response and response measurement used.

Other effects, of lesser importance but worthy of mention, included the Ss' standing position, which apparently favored azimuth determinations slightly, and reflection from the grassy surface, which may have been responsible for some of the most extreme errors found in Study IV. However, the data from Study VI did not support either of these explanations.

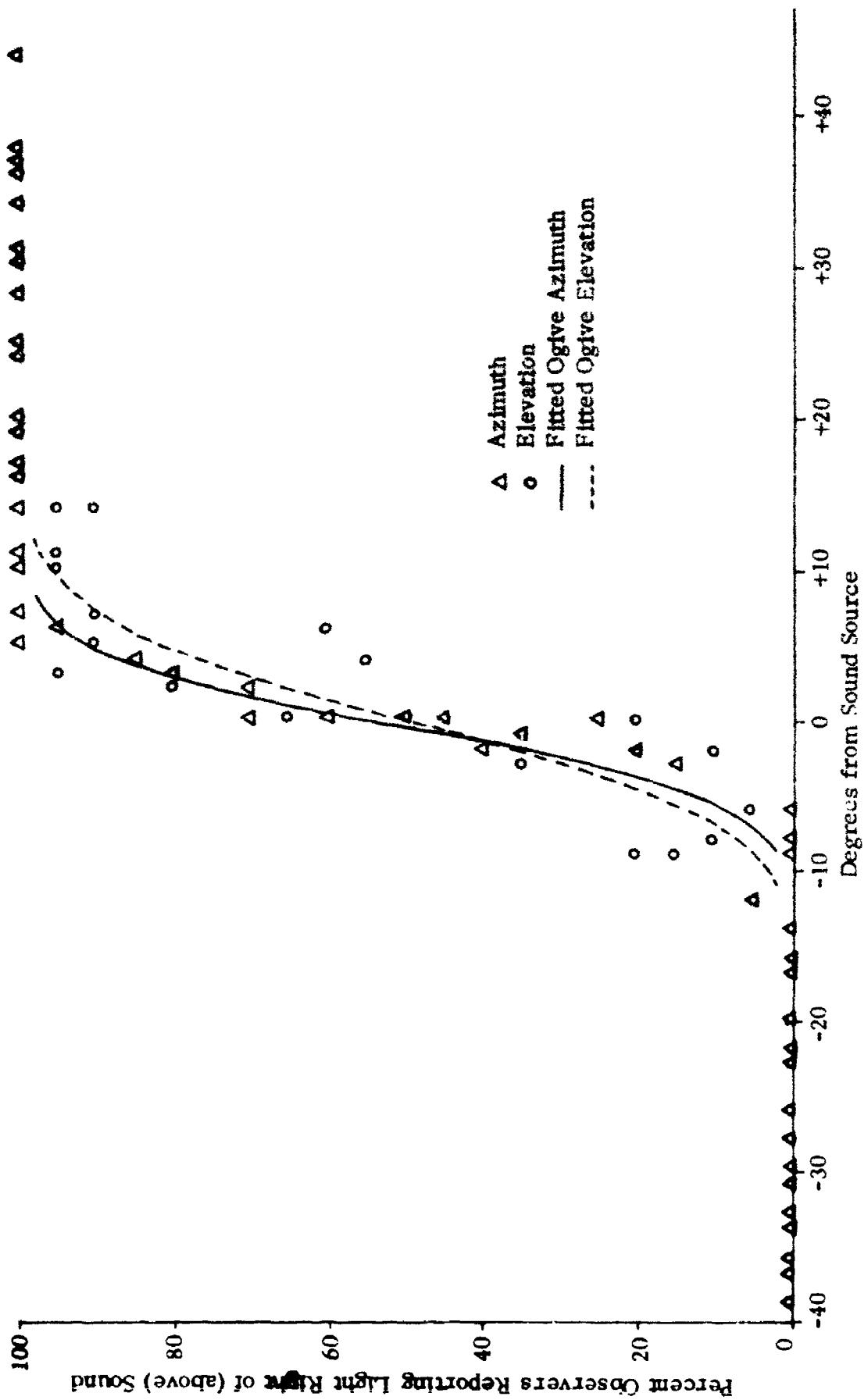


Fig. 5. STUDY VI: STANDING POSITION, COMPOSITE
(All points translated to zero.)

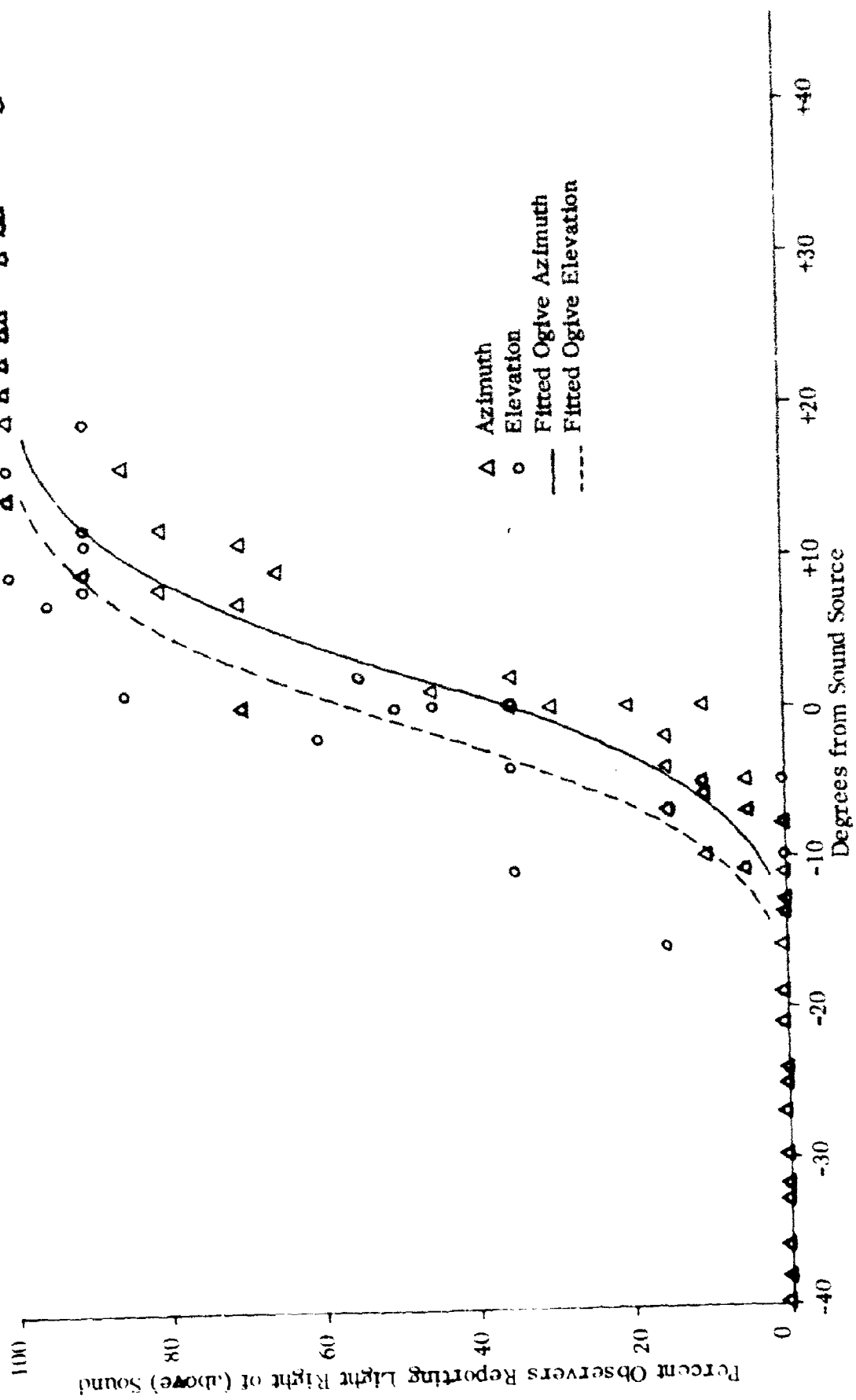


Fig. 6. STUDY VI: RECLINING POSITION, COMPOSITE
(All points translated to zero.)

Hearing Defects

One hypothesis was that hearing deviations might affect azimuth localization. Of the 40 Ss who localized noises in Study IV, 19 showed deviations of at least 15 dB at one or more of the frequency levels (500, 1000, 2000, 3000, 4000, 6000 cps). Deviations of this size suggested that these Ss had hearing defects or had sustained hearing damage in their prior experience. Nine of these deviant Ss had responded to the vertical (elevation) array, and ten to the horizontal (azimuth) array. Separate t tests showed no significant differences between the normal and the deviant group on azimuth localization. However, the deviant group was significantly less accurate on elevation localization ($p < .01$).

Hochberg's study (4) of interaural disparity in hearing levels suggested a more subtle analysis. Hochberg found that hearing disparities were related to localization ability when the average interaural disparity was 21 dB or more. He determined the average interaural acuity by averaging the differences between the audiometric thresholds for each ear at 2000, 4000, and 8000 cps, regarding the higher frequencies as more discriminating for localization. Hochberg worked with Ss who had essentially normal hearing, but his method of analysis could be extended to the 40 Ss in this study. Our Ss were divided into three groups: (a) a normal, non-deviant group; (b) a group with "balanced" hearing defects, i.e., less than 21 dB interaural disparity; and (c) a group with "unbalanced" hearing defects, i.e., interaural disparities of 21 dB or more. From Hochberg's work, we hypothesized that the third group, with lateral mean differences of 21 dB or more, would have significantly degraded auditory localization. The three groups' mean absolute errors are shown in Table 2.

TABLE 2
Interaural Disparity and Auditory Localization

Group	No. of Subjects	Mean
Normal	21	8°
Lateral balanced	13	13°
Lateral unbalanced	6	11°

Neither Duncan's range test nor t tests indicated any significant differences among the three groups. Thus Hochberg's findings with normal (but disparate) S_s was not confirmed in this group, which included more severe hearing defects.

The general proposition that hearing defect would be associated with greater errors in azimuth localization was tested separately for the S_s in Studies IV, V, and VI. In each group, an individual was classified as defective if he showed a deviation of 15 dB or more above zero threshold at any of the frequencies tested -- 500, 1000, 2000, 3000, 4000, or 6000 cps. The breakdown of the three S groups and the results of the t tests are given in Table 3.

TABLE 3
Hearing Defect and Auditory Localization

Study	Defect Group			Normal Group			t
	No. of Subjects	Mean	Standard Deviation	No. of Subjects	Mean	Standard Deviation	
IV	10	-1.09	3.60	10	-1.90	2.86	0.55
V	9	-0.97	3.04	26	0.15	2.49	0.99
VI	11	-0.90	2.70	9	0.30	3.44	0.85

None of the t values in Table 3 were significant; the differences in means between normal and defect groups can, therefore, be attributed to chance. This result, replicated three times, casts serious doubt on the previously reported finding that S_s with hearing deficiencies make larger errors (1). It appears more likely, in view of these findings, that any azimuth errors associated with lateralized hearing loss are reduced or eliminated with further experience by an adaptive process similar to the recovery of lateralization demonstrated experimentally by Elfner and Carlson (3).

GENERAL DISCUSSION

Azimuth errors in localizing fixed noise sources in these studies were generally smaller than errors obtained in previous studies of moving noise sources (helicopters in flight) (1). That finding is, of course, predictable. Contrary to prediction, however, elevation errors were not significantly larger than azimuth errors, after elimination of instrumentation artifacts. In other words, elevation errors and azimuth errors were approximately the same size. It is also interesting that pointing at auditory targets was as accurate as aiming at them, as long as there was no visual cue to the target location.

Several problems in auditory localization deserve further consideration. The results of these experiments in open-field conditions have probably been affected by uncontrolled environmental variables, such as reflection and absorption of sound by ground cover. Some of these variables can be controlled under laboratory conditions. If further experimentation under better-controlled conditions supports results obtained thus far, it can be predicted that elevation errors and azimuth errors will be approximately the same size, averaging less than 5° (plus or minus) for stationary noise sources. Furthermore, Ss with deviant audiometric patterns should show no significant impairment in localization ability, unless the deviation involves a recent unilateral threshold change or a gross interaural disparity. Even with a recent change in threshold, adaptation is probably rapid, with a return to "normal" localization ability after as little as two to four days of experience.

SUMMARY

This report summarizes three recent studies in which Ss localized stationary noise sources at a constant distance in darkness. In each study angular errors in azimuth and in elevation were measured. Two different response methods were compared, and these methods yielded somewhat different results. Pointing at auditory targets in darkness was found to be as accurate as aiming at them. The first study showed a large difference between azimuth and elevation errors, but this difference was not confirmed in the subsequent studies. Contrary to suggestions from earlier studies, Ss with hearing deviations (defects) localized sounds as well as non-deviant (normal) Ss did.

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